ANALYSIS AND EVALUATION OF THE PHYSICAL CHARACTERISTICS OF HOT MIX ASPHALT USING CRUMB RUBBER MODIFIER

Benjamin Colucci, Ph.D., PE
Principal Investigator
Civil Engeneering Department
bcolucci@rmce02.upr.clu.edu

Jose A. Colucci, Ph.D., PE
Co-Principal Investigator
Chemical Engineering Depatment
j_colucci@rumac.upr.clu.edu

University of Puerto Rico
Mayagüez Campus
PO Box 5000
Mayagüez, PR 00681 - 5000

Jorge Velar, MSCE, EIT
Research Assistant
Engineering & Technology Department
j_velar@cutb.upr.clu.edu

University of Puerto Rico
Bayamón Campus
Minillas Industrial Park
Building No. 170, Road PR-174
Bayamón, PR 00959

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Executive Summary

State-of-the-art technology is available which incorporates shredded scrap tire rubber known as crumb rubber modifier (CRM) as a modifier for asphalt cement in paving mixtures. CRM is the general term to describe all rubber particles obtained from the shredded of discarded tires which are reduced up to a size of 6.35 mm. Two technologies are most commonly used to incorporate crumb rubber in asphalt pavement applications, namely, the wet and dry process. The wet process, also known as the modified binder method, covers any method that blends the crumb rubber with the asphalt cement (AC) prior to incorporating the binder. The dry process applies to technologies that mix the crumb rubber with the aggregate prior to being charged with the asphalt binder. In 1991, the Intermodal Surface Transportation Efficiency Act (ISTEA), Section 1038, mandated the use of CRM in asphalt paving mixtures for all states including Puerto Rico. This report describes the first major research effort conducted at the University of Puerto Rico at Mayagüez (UPRM) to characterize hot mix asphalt (HMA) paving mixtures using crumb rubber as a modifier.

A comprehensive literature review on pavement uses of CRM, processes, specifications, and legislation was conducted. Based on this research, it was determined that the wet process is the most viable technology to be implemented in Puerto Rico, due to it ability in delaying the aging process of the asphalt binder and increases the binder's ability to hold aggregate in place.

A factorial half-fraction experimental factorial design (2^{5-1}) was then performed to evaluate the effect of different levels of critical variables on the physical properties of the binder and the asphalt concrete mixtures. The variables evaluated in the experimental design to assess the effectiveness of crumb rubber as a binder modifier or as an aggregate in asphalt paving mixtures included the effect of rubber particle size, percent of rubber, asphalt type, reaction time, and reaction temperature. Reaction time, temperature, and type of additives were evaluated to determine the critical rubber-asphalt reaction parameters that might affect the desirable physical characteristics of the modified binder. In the *particle size* parameter an ultra fine gradation of CRM was selected (passing the 40 and 80 mesh) based on the positive Florida and New Jersey DOT experience. The lower and upper limits of *rubber percent* were established at 5% and 20%, respectively, to verify the engineering criteria documented in the Florida DOT specification since it has similar climatic characteristics as those encountered in the Island.

The *viscosity graded asphalt type* AC-20 and AC-30 were the lower and upper limits, respectively, since they are the most common types of AC used on the island.

A lower *reaction time* limit variable was established at 15 minutes, based on Florida DOT experience and the upper value of 120 minutes was chosen based on the literature review.

For *mixing temperature* a maximum of 176°C was established following the recommendations of a Rouse Rubber publication, as well as to be on the safe side with respect to the flash point of the asphalt cement. The lower bound was set at 150°C to comply with the Florida DOT specification.

A pilot reactor plant was used to prepare the modified binder following the wet process. A Brookfield viscometer was used to characterize the viscosity of the modified binder. Different blends of the most common types of gradations used by the Puerto Rico Highway and Transportation Authority as well as the aggregate sources for hot mix asphalt surf'ace (S-1) and base courses (B-1) were evaluated in terms of their stability and void analysis and compared with test results obtained with the modified crumb rubber mixes.

The analysis of the physical characterization of the asphalt rubber was divided into two tasks, namely the characterization of the binder in terms of Brookfieid viscosity, penetration (AASHTO 49), and ductility (AASHTO T51) test.

The results of the *binder physical characterization* confirms the findings documented by SHRP for the virgin AC. The major findings in terms of the *Brookfield viscosity* are summarized below:

- The velocities at which tests were conducted, if greater than 12 rpm, did not have any effect on the final viscosity readings.
- The unmodified asphalt cement stabilized very quickly after the spindle had initiated its rotation (test duration).
- The tendency has been that at low temperatures (lower than 163 °C) the AR is not very stable or homogeneous within the first couple of minutes of the test (ten minutes for 149°C); the drop is in the magnitude of 15 Poises, and after that, the decreasing rates stabilize. In the case of temperatures near 163°C the first ten minutes the drops in viscosity are about 2 Poises. At higher tempera tures, in the neighborhood of 177°C, the viscosity vs. temperature curve is less smooth than in the previous cases, which means that the AR has started to degrade.

- In general, asphalt binders modified with crumb rubber have greater viscosities than the conventional viscosity graded binders (i.e., AC-20 and AC-30), for the same testing temperature.
- The effect of the rubber content in the modified binder is directly proportional to its viscosity; with any increase in rubber contents, the viscosity increases.
- If the maximum size of the rubber particles increases (sieve 80 to 40), the viscosity of the asphalt modified with rubber also increases.
- There is an interaction between temperature and time of reaction. In other words, the combination among these elements that activates all the rubber will create higher values of viscosity. Examples of such coin binations are:
  - High temperature and high time of reaction
  - Low temperature and high time of reaction
  - High temperature and low time of reaction

The major findings in terms of the penetration and ductility are summarized below:

- In general, the test results for the penetration test are inversely proportional to the CRM contents, which is associated with the increase in viscosity.
- The Penetration averages are 41.87, and 57.62 units when the rubber percentages are 20 and 5, respectively. Similarly, the penetration averages for the asphalt binder are 47.37 and 52.12 units when the reaction times are 15 and 120 minutes, respec tively.

- It was observed that the smallest penetration average (38 units) was found with the following factor combination: 20% of rubber, 15 minutes of reaction time, arid l50°C of temperature
- The average penetration reductions were 15 and 26 percent for the 5% and 20% of CRM contents, respectively compared to the virgin binder
- The average ductility is 21.88 and 28.28 cm. for the rubber type 40 and 80, respectively. Thus, the rubber type SO should be used in order to increase the ductility of asphalt binder.
- The ductility can be increased by selecting the 80 mesh rubber type.
- The average ductility reduction was 80 percent for both the 5% and 20% CRM contents.
- The penetration and ductility tests were successfully performed within the precision statement of their respective standards without any problem and/or erratic results such as those reported in the literature.
- Both consistency tests can be considered adequate indicators of the physical characteristics and homogeneity of the modified asphalt binder, if the acceptance range is redefined.

Modified asphaltt surface and base type mixtures were prepared, compacted and tested using the density and voids analysis procedure, Marshall stability, flow, density, air voids, voids in the mineral aggregate (VMA), and voids fill with asphalt (VFA) for the locally available aggregates typically manufactured in Puerto Rico (i.e., pit crunched stone and screening and coarse river sand).

The major findings of the *density and voids analysis* can be summarized as follows:

- As was the case with the conventional viscosity graded asphalt, CRM modified asphalt showed no significant difference in engineering properties among AC types.
- Due to the grading composition of the traditional black base type mixtures, which essentially tend to be more open graded than surface mixtures, showed a better interaction with the CRM titan the dense graded surface mixture (S-1).
- The factors that affect the properties of the asphalt concrete mixture (i.e, reaction time and temperature) show a major dispersion of the data with low contents of asphalt cement as compared to those modified with CRM 5%), which tends to close with increases in binder contents of the mixture.
- The CRM contributes to the increase in the Marshall stability results. Comparing the values of the Marshall stability obtained for the same binder content between the surface mixtures without CRM and those obtained in the surface and the base mixtures modified with CRM, it can be seen that the CRM values exceeded those obtained with the conventional HMA paving mixtures. This stability increment allows us to consider using modified base mixtures instead of the conventional surface base mixture.
- During the batching process of the asphalt concrete with 20% rubber, a strong rubber odor and high emission of gases was observed at the laboratory. As a resultt of this incident, and considering the potential environmental hazard that it would have in full scale plant production, the 20% rubber content was discarded from the void and density analysis.

- During the production of the modified binder, technical difficulties were encountered associated with small amounts of rubber particles that stick to the surface of the paddles (especially for the 20% contents). Therefore, this mixing method was not feasible for testing minor changes in the rubber contents.
- The results of the Standard Test Method for Quantitative Extraction of Bituminous Paving Mixture (ASTM D 2172) showed that the standard procedure is appropriate for determining with great accuracy the contents of asphalt and crumb rubber as a whole. On the other hand there is no standard method to properly determine the rubber contents in the asphalt binder by itself, after it has been modified.

Based on the findings of this study, the following conclusions and recommendations are made:

- The wet-process is the most cost-effective for Puerto Rico, however, since the local asphalt plants do not have the RAP feeding system needed for the dry process. Also the wet process has better potential for addressing the typical asphalt pavement defects encountered on the island.
- In order to implement the wet process in Puerto Rico's existing asphalt plants, the initial cost of the blending unit trailer would be relatively high (prices start at $250,000), associated with changes to the drum mixer. This cost would be reflected in the final product; we estimate a 67% increase in cost for CRM HMA as compared to current dense-graded asphalt unit prices (i.e., $40/ton in place).
- In terms of optional CRM contents, 20% is too high due to the problem of fumes emission and odor encountered in the laboratory. A 5% crumb rubber

is acceptable since of provides a workable binder that will modify its engineering properties, making it superior for tropical conditions in which rutting is not a typical failure.

- In terms of the voids and density results, there is no significant difference for AC-20 and AC-30.
- Reaction time and mixing temperature are factors that influence significantly the voids and density analysis.
- Crumb rubber should be used in mixtures with a low content of fines, as is the case of B-1 arid L-2 (typical base course and leveling mixtures used in Puerto Rico, respectively)
- Crumb rubber modified mixtures should be used in areas of low traffic volume, as is the case of shoulders, base Layer, and pavement segments that are not located on the primary highway network.
- Future research is needed to address CRM contents other than 5 and 20 percent and proper procedures other than the traditional quantitative asphaltt extraction test method.
- Different spindles and rpm combinations should be tested to minimize the amount of rubber that are adhered to the spindle within the batch process and could provide a better and homogeneous asphalt rubber mixture
- Pilot test sections should be constructed in order to properly analyze CRM performance subjected to traffic loads and climate conditions typically encountered in Puerto Rico.
- Incentives should be given by the responsible agencies for the proper management and disposal of scrap tires, due to the fact of the immediate

benefit that this emerging technology will bring to assist in solving this environmental problem.

- The effects of this technology are more significant when the pavement is subjected to changes in temperature, such as those encountered in the northern states of the mainland US.
- In summary, even though the engineering characteristics of hot mix asphalt are improved with the inclusion of CRM, the initial investment and the potential risks associated with the full implementation of this technology make it less likely to be fully adopted by the Puerto Rico Highway and Transportation Authority as part of their standard specifications for road construction. However, a life-cycle cost analysis should be made in order to provide realistic estimates regarding economical feasibility and the expected rate of return of this technology. This life-cycle cost analysis should include cost increases due to higher binder and CRM contents and the acquisition and maintenance of the mixing unit, versus the enhanced engineering properties of the modified binder.